



CHAPTER 4

Manufacturing Technology

U.S. metalcasters have been striving to improve the timeliness, productivity, and efficiency of their operations while delivering consistent, high-quality castings at competitive prices. Continued progress in developing advanced design and manufacturing technologies is paramount to the financial success of the industry in increasingly competitive international markets for metal parts and components.

Current Situation

The manufacturing component of the metalcasting industry is extremely diverse and includes sand casting, investment casting, lost foam casting, die casting, permanent mold casting, and others. Various forms of sand casting dominate, accounting for about 60% of the volume (by weight) of castings. Permanent mold and diecasting combined account for another 20% of the total by weight, while investment casting has increased to 7% of the total. Exhibit 4-1 indicates the casting methods used in U.S. foundries, including the value of shipments by casting method.

Some key factors in evaluating the current state of casting manufacturing include:

- Lead time
- Productivity
- Quality and consistency
- Energy efficiency
- New or alternative processes

The **lead time** that it takes to bring a cast component from concept and design into production is critical to increasing castings' share of new markets. Typical casting lead times run into months for small parts with moderate complexity. For example, steel castings typically take 20 to 40 weeks to procure; "best practice" can bring this time down to about 4 weeks in some cases. The major contributors to lead time in cast components are tooling construction and process development.

Productivity is one of the most important factors affecting the competitiveness of the metalcasting industry, especially in light of the fact that there is an excess production capacity in the industry worldwide. Over the last 15 years many metalcasters have refocused their efforts to improve productivity. Most of the automotive industry's producers of metal castings and finished cast parts are large foundries who have computerized every phase of their production operations. The productivity of these foundries and other large U.S. foundries is estimated to be comparable to that of major foreign competitors. The average metal yield in the casting industry, also an indicator of productivity, is approximately 50%.

Exhibit 4-1. Casting Methods Used and Value of Castings Shipped by U.S. Metalcasting Facilities (1994)		
Method	Use (%)	Value of Shipments (\$ billion)
Sand	60.0	10.4
Permanent Mold	11.0	1.8
Die	9.0	7.6
Investment	7.0	2.3
Other (Subtotal)	13.0	0.9
Shell Mold	7.0	--
Centrifugal, plaster, and evaporative pattern	6.0	--
TOTAL	100.0	23.0

Sources: *A Technology Vision and Research Agenda for America's Metalcasting Industry*, American Metalcasting Consortium, February 1995.
A Vision of the Future of the U.S. Metalcasting Industry, Idaho National Engineering Laboratory, September 1994.

The U.S. metalcasting industry has also made great strides in improving the **quality and consistency** of its products over the past 15 years in order to survive in the face of reduced demand. Typical scrap rates are currently only a few percent compared with rates in the 10 to 20% range during the 1970s and early 1980s. This improvement has occurred in spite of the fact that today's higher quality requirements necessitate scrapping many castings considered acceptable 15 years ago. However, even a few percent of castings scrapped translates into more than \$50 million annually in wasted manufacturing costs.

In general, the quality of U.S. iron castings is considered to be higher than Pacific Rim and South American castings but lower than German and Japanese castings. U.S. steel castings are considered to be essentially equal in terms of quality as their major competitors. Non-ferrous castings made in the U.S. are considered to be of higher quality than Japanese castings and only slightly lower in quality than German castings.

The U.S. metalcasting industry's annual **energy use** is estimated to be about 250 trillion Btus. Most of the energy is used for major operations such as melting, molding, and heat treating. The major fuels used are electricity and natural gas. Energy costs account for an estimated nearly 25% of the cost of diecasting products; for other industry segments, energy is estimated to account for 15% of total product cost.

The energy efficiency of equipment used in U.S. foundries has been estimated at less than 45%. Cupola furnaces, still used by some iron casters, are less than 35% efficient. These furnaces are slowly being replaced with coreless induction furnaces that are 75 to 80% efficient.

A number of **new casting processes** have recently been developed and others are emerging. Investment casting and lost foam (expendable pattern) casting technologies have proven to be adept at new designs that

displace complex machined or fabricated parts, and may provide new product and application opportunities. Thin-wall casting techniques can be used to produce castings with superior mechanical and physical properties at lower weights, leading to growth of cast metals in the automotive, aircraft, and other markets. Two relatively new thin-wall casting processes -- the Cosworth process for non-ferrous castings and the FM process for ferrous castings -- have been developed for producing clean, thin-wall castings. However, further understanding of all of these processes needs to be obtained to realize their full potential.

Trends and Drivers

Each of the key manufacturing factors described above is an integral part of the overall process of producing a casting. The combination of increased competitiveness and more demanding customers has put more pressure on metalcasters to improve their performance as measured by these factors.

The **lead time** required to get the first article delivered to the customer is a critical factor in the competitiveness of metalcasting versus other fabrication techniques. Traditionally, metalcasters are not always able to respond quickly to changes in the customer's design (and vice versa). The U.S. metalcasting industry is continuing its efforts to cost-effectively develop and produce castings faster (or just-in-time) while improving casting quality and consistency.

The lead time to produce a casting depends on a number of factors, especially the availability of and reliance on computer-based tools. New computer-based technologies are improving capabilities in casting design, prototyping, process development, control, and production. Emerging technologies in computer hardware, CAD/CAM software, computer modeling (including solidification modeling), rapid prototyping and rapid tooling make design and development of cast metal prototype components easier, faster, and more accurate. Those casters who use rapid prototyping techniques have significantly reduced the time required to produce a casting from a concept or CAD design.

Casting lead time is affected by the availability of standardized data on specific properties, data that are limited even though cast components have been used for over a century. Designers often use "case histories" of comparative components as their guidelines for new designs. This design method limits the ability to make changes, as illustrated by the months required to design a radically new component. The variation in data on casting properties also hurts the more advanced casting designers who use finite element modeling interfaced with CAD/CAM programs to develop cast metal components. Predictive software used to design parts and molds can eliminate the high cost of trial-and-error runs or expensive tooling modifications if rules for dimensional control are known.

The **productivity** of the casting process is crucial to the survival of the U.S. metalcasting industry. Improvements in the industry's productivity have been steady. New automation and computer-based technologies are improving casting control and production. Modern computational hardware and software tools can greatly streamline and modernize casting production. Robust, reliable sensors can be linked to computers to control a process and its critical parameters in real time. Process control computers can in turn be linked to production flow computers to form a network that controls an entire foundry. However, few foundries can afford these technologies and systems. Continuing technological advances in achieving greater precision in patterns and tooling, and also tighter tolerances in production machinery and molding media, can yield parts that meet design and performance specifications with minimal seconds operations. Casting **quality and consistency** are important factors in determining the successful application of castings in both current and new markets. The quality (specifically metal cleanliness, mechanical properties, and dimensional accuracy) of castings affects the manufacturing costs of products containing castings. Many

high-alloy and other high-value-added castings that were sourced off-shore during the 1980s are now returning to domestic foundries because of improved exchanged rates and the inability of foreign foundries to meet, on a continuing basis, the quality and delivery requirements of domestic customers.

Casting customers are increasingly demanding higher quality castings; more and more casting suppliers and customers consider zero-defect castings as a production objective. The pressure of the customer on the metalcaster to deliver a higher quality product faster will be exceeded by the metalcaster's own needs to optimize his manufacturing process for lower overall costs and quicker response. Through improved process and quality controls, mold and casting scrap can be minimized, thus significantly improving both casting quality and productivity.

The **energy efficiency** of casting processes directly impacts the cost of the casting, providing casters with an incentive to reduce their energy use. Melting processes have the largest energy requirements in the foundry; in some cases, inefficient cupola furnaces are being replaced with more energy-efficient electric furnaces.

New manufacturing processes are needed to produce the light-weight, high-strength, and thin-wall components essential to competing in new and emerging markets. For example, the development of lost foam casting has created new opportunities to expand casting applications with new products. Components cast to near net shape (which reduces machining) will be increasingly common in the future.

Performance Targets

In *Beyond 2000: A Vision for the American Metalcasting Industry*, the industry identified a number of performance targets related to manufacturing and environmental issues. While the original indication was that these goals were to be achieved over the next 20 years, they have been modified by the industry for achievement within five years:

- Increase productivity 15%
- Reduce average lead time 50%
- Reduce energy consumption 3 to 5%

While the original goals represented a good starting point, there was general agreement that they were too conservative for the 20-year time horizon. The manufacturing goals to increase productivity and reduce energy consumption are thought to be relatively easy to achieve in the next several years with existing technologies. A more aggressive, but achievable, goal for productivity by 2020 is to produce *twice* as much with the same amount of people. On an interim basis, the industry should strive to achieve a 15% increase in productivity (measured as tons produced per production worker) every five years.

Likewise, the goal to reduce by 50% the average lead time required to manufacture a casting is thought to be achievable over a 5-year time horizon rather than 20 years. Many customers would probably like to see lead times reduced by even more (75 to 80%). Energy efficiency can also be improved at a faster pace; by 2020, the industry should endeavor to reduce the amount of energy consumed per unit value of shipments by 20%, with interim reduction targets of 3 to 5% every five years.

Technology Barriers

A number of challenges lie ahead for improving manufacturing technologies in the metalcasting industry. These challenges, or technology barriers, are shown in Exhibit 4-2. They are categorized as follows:

- Manufacturing
- Sensors and controls
- Modeling
- Lead time
- Productivity
- Quality and consistency
- Energy
- Cross-cutting

Customers are pressing for quicker turnaround times and have needs for products with increasingly higher levels of dimensional accuracy. Other **manufacturing** barriers include a lack of rapid die casting technologies, metal handling capability limitations of much of the existing metalcasting equipment used in the industry, and a fundamental lack of knowledge concerning scrap generation. In addition, not enough is known about some of the newer casting processes, including lost foam, FM, and Cosworth. The small size of the average foundry limits the ability of the industry to allocate major capital outlays for unproven technology. As a result, it is easier to make progress on incremental improvements than to introduce technologies that require major redesigns of manufacturing processes and casting techniques.

The lack of low-cost and accurate **sensors and controls** hurts metalcasting productivity and quality. The sensor and control equipment that is currently being used in die and sand casting is often not very effective. For example, there is a lack of continuous monitoring capability in sand molds, and existing sensors are unable to detect subtle changes in conditions in molds, gates, runners, and risers. While more automation of casting processes could be beneficial, particularly in improving dimensional accuracy, increasing productivity, and reducing lead times, the automated control systems currently in use are neither sophisticated enough to learn from past mistakes nor an adequate substitute for manual controls.

Linking advanced sensors and controls with new **computer models and analysis tools** holds great promise for the industry. Model developers face several technical challenges. The casting process is extremely complex, which makes the integrated modeling of the various process steps particularly difficult. Modeling runners and gates is particularly difficult. Modeling enhancements could help with defect reduction, but adequate models of turbulence in the casting process have not yet been developed. Also interfering with advancements in modeling is the lack of consistent data for mold filling and an inability to predict the micro-structure as a function of composition and processing.

Chief among the barriers to reducing **lead times** is the amount of trial and error that is currently needed to develop and set up tooling equipment. Other key barriers are the lack of effective scheduling software and the need for rapid tooling technologies that can be used to manufacture customized products in smaller lots. The lack of three-dimensional part descriptions and the typical absence of calculations of expected results during the design phase also present problems.

Exhibit 4-2. Major Technology Barriers in Manufacturing
(Most Critical Barriers Boldfaced)

AREA	BARRIERS
Manufacturing	<p>Difficult and expensive to achieve higher levels of dimensional accuracy</p> <p>Using new technologies is costly and funds for capital outlays are scarce</p> <p>Many of the causes of scrap generation are not known</p> <p>Lack of rapid die-casting technologies</p> <p>Lack of materials other than steel for die casting dies</p> <p>Limited capabilities of existing equipment for metal handling</p> <p>Soldering problems in die tools</p> <p>Present understanding of the lost foam process is considered deficient in several key areas</p> <p>Lack of full understanding of the FM process and the Cosworth process; specific issues include increasing dimensions, cleanliness, and soundness</p>
Sensors and Controls	<p>Lack of continuous monitoring of sand in molds</p> <p>Automated controls are incapable of learning</p> <p>Current sensors cannot detect subtle changes</p> <p>Don't know when control algorithms are optimized</p>
Modeling	<p>Modeling runners and gates is hard due to complexities</p> <p>Inability to model turbulence for defect reductions</p> <p>No consistent data for mold filling</p> <p>Lack of fundamental understanding of the microstructure of materials</p> <p>Mold designs are not fast or intuitive</p> <p>Problems with system compatibilities between processes (computer and other)</p>
Lead Time	<p>Customization for smaller lots requiring rapid tooling</p> <p>Too much trial and error in tooling development</p> <p>Lack of effective scheduling software</p> <p>Lack of 3-D description of parts</p> <p>Lack of understanding of process flow</p> <p>Lack of engineering discipline - design expertise</p> <p>Lack of software that puts on the gates and risers</p>

Exhibit 4-2. Major Technology Barriers in Manufacturing
(Most Critical Barriers Boldfaced)

AREA	BARRIERS
Lead Time (cont)	<p>No calculations of expected results during design phase</p> <p>Failure to communicate changes in product requirements</p> <p>Lack of process versatility commensurate with materials versatility</p> <p>Businesses require back-logs</p> <p>Industry is vertically disintegrated</p> <p>Typically it takes longer for concept development, tooling production, and prototype delivery of castings than alternative product forms</p> <p>Long lead times limit the use of castings in new component designs</p>
Productivity	<p>Too much labor in the cleaning room (post-casting processing)</p> <p>Lack of robust productivity sensors</p> <p>Lack of process models that adequately describe metalcasting processes</p> <p>Casting yields that are less than optimal increase the costs of castings, making them less economical compared with more expensive fabricated components such as welded assemblies or forgings</p> <p>The rules currently used in designing gating and pouring systems are at best empirical, contributing to low casting yield and quality</p> <p>Too much downtime</p>
Quality and Consistency	<p>Too many inclusions</p> <p>Gaps in knowledge about the conditions that cause the different types of casting defects inhibit the ability of casters to modify and control casting processes to eliminate defects</p> <p>Perceived soundness issues have prevented castings from being considered for many critical applications</p> <p>Inability to test molten metal quality "in real time"</p> <p>Lack of consistency in the soundness of castings has prevented them from being treated as forgings or weldments.</p> <p>Lack of directional solidification during casting</p> <p>Molding processes that have typical tolerance recognition are extremely conservative in their capabilities prediction, giving a poor perception of the dimensional accuracies attainable with common casting processes</p> <p>Problems with dimensional control hurt the ability of some producers to assure potential customers that their tolerances can be met</p> <p>The complex injection profiles used by die casters are less than optimal because of a lack of</p>

Exhibit 4-2. Major Technology Barriers in Manufacturing (Most Critical Barriers Boldfaced)	
AREA	BARRIERS
	knowledge about the transition between the different portions
Energy	Lack of robust sensors and controls suitable for hostile environments Lack of understanding of process flow Long heat treating times Energy wasted in metal melting High temperatures for handling metals may not be needed The melting processes used in metalcasting are not controlled as well as those in wrought steel production, leading to higher energy intensity in metalcasting Inadequate understanding of material/process interactions and process fundamentals related to induction hardening Relatively low cost of energy
Cross-Cutting	Lack of educated workforce Existing knowledge base is not being applied Metalcasting is not a time-efficient, low-cost manufacturing process Lack of systems to identify scrap at early stages of process where value added components is low Poor equipment choices

Some lead-time barriers also relate to the structure and practices of the industry—for example, absence of vertical integration fragments a single job. In addition, the desire for order backlogs inhibits just-in-time scheduling in small job shops. Some cross-cutting barriers that have a significant impact on lead time include the scarcity of employees with strong engineering backgrounds as well as gaps in understanding process flow relationships. Both of these factors serve to limit the technical knowledge that can be applied to solve manufacturing problems. Poor communication between customers and casters about product requirements also inhibit improvements in lead times.

One of the most significant barriers to increased **productivity** is the lack of process models that accurately and completely describe metalcasting processes. In addition, available sensors and controls are not robust or sophisticated enough to measure and control all the process parameters. Another key problem is that far too much time and labor is spent to clean and process the products for final shipment after they have been cast. Less-than-optimal yields and equipment downtimes also hurt foundry productivity.

Casters feel that the level of inclusions in cast components is still too high. Barriers related to improved casting **quality and consistency** include lack of complete understanding of defects, which impedes casters ability to control or eliminate them. The lack of real-time techniques to test molten metal quality increases

the occurrence of defects. Other problems are related to dimensional control and directional solidification during casting.

The lack of advanced sensors and process controls that can withstand the hostile environments inside and around the melting and holding furnaces is a key barrier to achieving **energy efficiency** goals. Relatively inefficient uses of energy in melting metal and long processing times associated with heat treating are recognized problems in all segments of the industry. Other barriers include the relatively low cost of energy, the relative inefficiency of the melting process, long heat treating times, and a lack of complete understanding of induction hardening, which leads to some casters to use the more energy-inefficient carburizing process.

An important **crosscutting** barrier to achieving the industry's long-term goals is the lack of a technically educated work force. As equipment becomes more sophisticated and computer-based, and as the industry shifts from the image of making "commodity parts" to making high-quality "engineered components," more technical skill will be needed from the labor force. Other barriers arise from the inherent nature of the metalcasting process, which is not a time-efficient, low-cost process. Poor equipment choices contribute to poor performance; as in many other facets of foundry operation, the knowledge that exists is not necessarily being applied.

Research Needs

The research that the industry believes is needed to overcome the technology barriers in manufacturing (shown in Exhibit 4-3) fall into the following areas:

- Fundamental understanding
- Design aids
- Processing technologies
- Mold technologies
- Sensors and controls

A critical area of research that will rely heavily on government funding is the development of a better **fundamental understanding** of metalcasting processes. A top research need is to improve the ability of metalcasters to produce to size or dimension. Examples include the use of low-expansion sand in lost foam or the use of "three-dimensional shrink factors" in die casting. Successful research in this area would help the industry make progress towards three goals: improved productivity, reduced lead time, and reduced energy consumption. It is possible that this research, if supported by the government, could yield commercially applicable results in the near-term (within three years).

An investigation of the die casting process to determine the mechanisms by which die casting dies actually fill would help the die casting industry improve its productivity. This is a long-term research effort that would require government funding to complete. Developing an understanding of folds for aluminum lost foam casting and methods to improve yields are two high-priority research needs in the area of fundamental process understanding thought to be achievable within ten years.

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame

(**k** = Top Priority; **M** = High Priority; **F** = Medium Priority)

Time Frame	Fundamental Understanding	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
NEAR (0-3 Years)	<p>k Improve the ability to produce size/dimension</p> <ul style="list-style-type: none"> - the use of low-expansion sand in lost foam casting - the use of “3-d shrink” factors in die casting <p>Correlate thermal and physical properties to flowability in sand systems</p> <p>Database of the thermal and physical properties of sand molding systems</p>	<p>k Improve speed and accuracy of tool design simulation software</p> <p>Develop systems to support distributed design</p> <ul style="list-style-type: none"> - to improve collaboration among physically separated participants <p>Improve existing rapid prototyping processes for cast components</p>	<p>Ž Transfer understanding of current scrap analysis methods and remedies</p> <p>S includes an atlas of root causes, defects, and preventative measures</p>	<p>k For die casting (permanent molds), need capability to cast to shape</p> <ul style="list-style-type: none"> - use of cavities 	<p>k Develop a systems approach to scheduling and tracking</p> <p>M Develop robust sensors and controls suitable for hostile environment</p>
MID (3-10 Years)	<p>k Understand folds for aluminum lost foam casting</p> <p>M Develop understanding of what causes inclusions</p> <ul style="list-style-type: none"> - reducing defects will reduce waste <p>M Develop methods to improve yield</p> <p>M Improve the correlation between separately cast test bars versus the material in casting</p> <ul style="list-style-type: none"> - help improve design of castings 	<p>k Develop low-cost rapid tooling technology</p> <ul style="list-style-type: none"> - for both making and changing the tooling <p>M Develop design-for-casting methods and supporting systems</p> <ul style="list-style-type: none"> - e.g., CAD environments that help design/engineer castings <p>Develop better solid model casting design tools</p>	<p>k Cost-effective and dimensionally accurate patternmaking processes for use in sand casting</p> <p>M Improve lost foam casting process for steel casting segment</p> <ul style="list-style-type: none"> - energy improvement - dimensional improvement - yield improvement - lead-time reduction <p>M Develop the advantages of semi-solid metal casting (SSM) process</p> <ul style="list-style-type: none"> - for higher-performance (aluminum) 	<p>k Improve tooling design to reduce the time to market</p> <ul style="list-style-type: none"> - low-cost rapid tooling technology - both making and changing the tooling <p>Ž New molding processes for as-cast dimensional accuracy in sand systems</p> <p>Ž Dimensionally stable molding materials for sand casting that are environmentally benign</p> <p>S sand molding or core systems with low or no emissions</p>	<p>Ž Affordable, robust software for gating and risering</p> <p>F Methods to rapidly determine quality and dimensions</p> <ul style="list-style-type: none"> - e.g., tomography, real-time x-rays - develop data to verify gate-flow models <p>M Develop mathematical model that describes process and can control machine</p>

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame

(**k** = Top Priority; **M** = High Priority; **F** = Medium Priority)

Time Frame	Fundamental Understanding	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
MID (3-10 Years)			<ul style="list-style-type: none"> - more alloys - environmentally benign <p>M Demonstrate effective joining techniques for new and dissimilar cast materials</p> <ul style="list-style-type: none"> - to join new alloys (especially for automotive applications) <p>F Develop methods to produce thinner wall castings</p> <ul style="list-style-type: none"> - expand metal casting into new markets - improve energy efficiency - will depend on better dimensional control <p>Miniaturization of systems to reduce cost and increase utilization</p> <p>Integration of pattern core and sand mold systems to improve dimensional accuracy</p>	<p>I Die materials and coatings to eliminate solder and heat checks in permanent cast applications</p> <p>S search for die materials other than steel</p> <p>Develop better understanding of the mechanisms of dimensional change of mold materials during the processes of pouring and solidification</p>	
LONG (>10 Years)	<p>k Figure out how die casting dies actually fill</p> <p>I Model of micro-structure to determine residual stress and mechanical properties</p> <p>F Tie modeling to casting</p>	<p>M Develop better methods for describing parts</p> <ul style="list-style-type: none"> - describe shape, functionality design intent, materials, etc. - digital description 	<p>I Melting and pouring technologies that do not introduce gases to the process</p> <p>F Processing techniques with alloys that don't need heat treatment</p> <p>F Faster heat treating processes for both ferrous and</p>	<p>Smart molds for continuous monitoring</p> <p>Develop low-cost production mold technologies (vs. prototype)</p> <ul style="list-style-type: none"> - cheaper ways to make mold quickly that is dimensionally correct 	<p>k Smart controls and sensors for automation supervision</p> <p>M Develop automated system for gating location</p> <ul style="list-style-type: none"> - fully automated

Exhibit 4-3. R&D Needs in Manufacturing By Time Frame (k = Top Priority; M = High Priority; F = Medium Priority)					
Time Frame	Fundamental Understanding	Design Aids	Processing Technologies	Mold Technologies	Sensors and Controls
LONG (>10 Years)	processes to determine defects in the micro-structure F Develop modeling technology for all casting processes - include optimization of energy use F Develop relationships between process conditions, material attributes, and part attributes		non-ferrous materials Develop lost foam capability for iron and steel in addition to aluminum F Develop material that adheres to dies and does not have to be replaced each cycle	- recyclable - disposable	F Develop fast-response, closed-loop diecast shot cylinder controls

Another of industry's most critical tasks is to improve the correlation between separately cast test bars and the material that is actually in the casting. In the mid term, this will help improve the design of castings and make the overall process more energy-efficient and productive. Again, it is unlikely that industry will be able to pursue this research without funding support from the government.

Advances in modeling can lead to better fundamental understanding of various phenomena that can particularly benefit the industry's goals to increase productivity and reduce energy consumption. However, better data will have to be developed to support advanced models and automation systems for foundries and casting processes. Some high-priority R&D needs that fill this need include developing modeling technology for all casting processes (including optimization of energy use), relationships between process conditions and material and part attributes, a model of microstructure to determine the effect of residual stress on mechanical properties, and the capability to tie modeling to casting processes in order to determine defects in the microstructure.

In the area of **design aids**, the industry has determined the most critical need to be improving the speed and accuracy of tool design simulation software, which it feels could be accomplished in the near term. In the mid-term time frame, a high-priority need is the development of design-for-casting methods and supporting systems such as computer-aided-design (CAD) environments. A longer term need is the development of better methods for completely describing individual cast components, possibly digitally. As shown in Exhibit 4-3, several other design aids are needed to help design engineers communicate information about casting designs and create better original casting designs. This research contributes principally towards the goal of reducing manufacturing lead time.

New **processing technologies** can contribute to the industry's productivity, energy efficiency, lead time reduction, and environmental goals. Cost-effective and dimensionally accurate patternmaking processes are considered a top priority. Better documentation and transfer of current scrap analysis methods and remedies could provide benefits in the near term.

New manufacturing processes that enable production of thinner wall castings will provide new markets and contribute towards two of the industry's manufacturing performance goals -- improved productivity and reduced energy consumption. A pressing need in this area is to improve the lost foam casting process for manufacturing steel castings. This would greatly expand the industry's ability to cast dimensionally correct steel components with a higher yield, lower energy consumption, and shorter lead time. Likewise, developing the advantages of the semi-solid metalcasting (SSM) process for use with more high-performance alloys would expand metalcasting markets while improving the productivity and energy efficiency of the overall manufacturing process. These are both mid-term research efforts that will require government funding to fully pursue. Long-term processing needs include the development of cleaner melting/pouring technologies and minimization of heat treating processes for all alloys.

Technology advances would be particularly valuable for **mold technologies** and tooling designs to make them faster, cheaper, more precise, and accurate. A top priority research need identified by the industry is the development of low-cost, rapid tooling technology for both making and changing metalcasting tooling. Research achievements here would greatly reduce the lead time required to manufacture cast components.

A more near-term solution is research aimed at eliminating steps in the casting process and developing technologies capable of "casting to shape" by making better use of cavities. Additional mid-term research in mold technologies for sand casting could be the development of new technologies that can achieve as-cast dimensional accuracy; environmentally benign, dimensionally stable materials for sand molds; and die materials and coatings that eliminate the need for solder and heat checks.

Greater accuracy in the casting process, including the ability to predict and relate the properties of materials, would allow better process control and would reduce defects. To make further progress in this area in the long term, new **sensors and controls** are needed for automation supervision, and "smart" molds need to be developed that have continuous monitoring capabilities. A high-priority research need overall is the development of a systems approach to scheduling and tracking. This research is likely to be undertaken by individual companies in order to reduce lead times and improve productivity. Companies undertaking this research could expect to see commercial results in the near- to mid-term time frame.

Another pressing need is to develop methods for rapidly determining the quality and dimensions of cast components, which would improve productivity and reduce lead times. For example, tomography and real-time x-rays can be used to measure these characteristics during the manufacturing process. Both die and sand casting processes would benefit in the near term from new x-ray imaging systems that could gather real-time data to verify gate-flow models. This research could produce commercial results in the mid term, but is not likely to be undertaken in the absence of government funding support. Another priority is the development of fast-response, closed-loop controls for die-cast shot cylinders. In the mid term, the development of cost-effective software for gating and risering could help improve productivity, while new mathematical models that describe the process could be developed to control the machine.

Potential Government Role

The majority of the research needs identified as being most appropriate for government support are in the long-term research category, including needs for modeling and advanced processing technologies.

Government support is considered critical for virtually all of the R&D needs listed under “Fundamental Understanding.”

The overwhelming majority of the manufacturing technology research needs are unlikely to be pursued by industry in the absence of government funding support. Because the majority of the metalcasting industry is composed of small companies with very limited R&D budgets and in-house research facilities, all but the “business-critical” R&D will probably not be funded or performed by individual companies. Furthermore, to maintain the metalcasting industry’s international competitiveness, much of the identified R&D is required more quickly than industry can support on its own. Therefore it is essential that industry leverage its R&D activities by partnering with outside agencies to remain competitive.